Evolution of the Southwestern Edge of the Poike Volcano, Easter Island

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Introduction

A joint Belgian-Chilean biological mission, conducted by Prof. H.Dumont of the Department of Morphology, Systematics and Ecology of the Gent University (Belgium), visited Easter Island in the summer of 1990. During this expedition, which lasted a few weeks, coring operations took place in the crater lake of Rano Raraku in view of biological and palaeoecological research.

In parallel with the scientific activities of the biologists of the project, three co-authors of the present paper (M.D.D., P.D.P. and R.L.) made field observations and proceeded to a limited rock and soil sampling in the easternmost part of the island. This reconnaissance survey provided new insights into the geomorphological, pedagogical and environmental evolution of the southwestern, inland-facing side of the Poike volcano since the youthful lava flow that encircles the north and northeast rims of Rano Raraku was poured out and protected the area between Poike and Raraku against further marine erosion (Paskoff, 1978a & 1978b).

The geochronological results presented in the f allowing account were obtained by the first author (A.B.), in close collaboration with P.P., at the Department of Geochronology of the Brussels Free University (Belgium). Other K-Ar age determinations related to rock samples from the Poike stratovolcano are in progress and will be included in a forthcoming paper. Major- and trace-element abundances were determined by inductively coupled plasma atomic emission spectrometry at the Department of Earth Sciences of the Université de Bretagne Occidentale (UBO) at Brest (France).

Table I
Chemical composition of two lava flows from Easter Island
(major elements in wt.%; trace- and rare-earth elements in ppm)
(Anal.I.Vergauwen)

	RN67	RN83
SiO2	49.10	48.50
TiO2	3.27	3.70
A1203	14.95	14.58
Fe2O3	14.10	14.82
MnO	0.21	0.23
mgo	4.68	4.39
CaO	9.44	8.73
Na2O	3.23	3.38
K20	0.67	0.97
P205	0.43	0.54
H20+	0.04	0.00
Rb	12.4	16.5
Sr	289	295
Ba	142	158
SC	35.0	33.2
v	338	346
Cr	60	20.0
Co	42.0	37.0
Ni	31.0	12.5
y	52	67
Zr	240	298
Nb	29.4	36.1
La	28.7	38.3
Nd	39.0	50.4
Eu	2.8	3.6
Dy	9.5	11.5
Er	4.9	6.0
Yb	4.2	5.3

New K-Ar data

Radiometric ages of rocks coming from all over Easter Island were published from the middle of the seventies onwards (Baker et al., 1974; Clark and Dymond, 1974; Gonzalez-Ferrán et al., 1974; Bonatti et al., 1977). They made it clear that Poike is a relatively old volcano as compared to the other main volcanoes (Rano Kau, Maunga Terevaka) responsible for the construction of the island.

The earliest phase in the subaerial development of Poike goes back to about 3 Ma ago (Baker et al., 1974). It was followed by repeated eruptions of thin basaltic and hawaiitic lava flows and rare outbursts of pyroclastics that built up a symmetrical cone, probably approaching 5 km across, with a shallow, small summit crater that at the present rises 370 m above sea-level. The three trachytic domes located on the northern slopes of Poike are thought to be representatives of the later stage of activity of the volcano. Unfortunately, the highly altered state of the rocks forming these parasitic cones precludes any reliable K-Ar age determination.

Both the decline of the volcanic activity and the insularity of Poike gave a strong impulse to marine erosion. The latter resulted in the formation of high, near-vertical seacliffs on all sides of the volcano and a severe reduction of its landmass. Wave action is still going on all but the west and southwest sides of the volcanic edifice. Here, several lava flows issued from fissure-controlled lateral centers of Maunga Terevaka inundated the coastline of Poike bringing about the subaerial linkage between the two adjacent emerging volcanoes and protecting the cliffed area between Tongariki and Mahatua from further marine erosion.

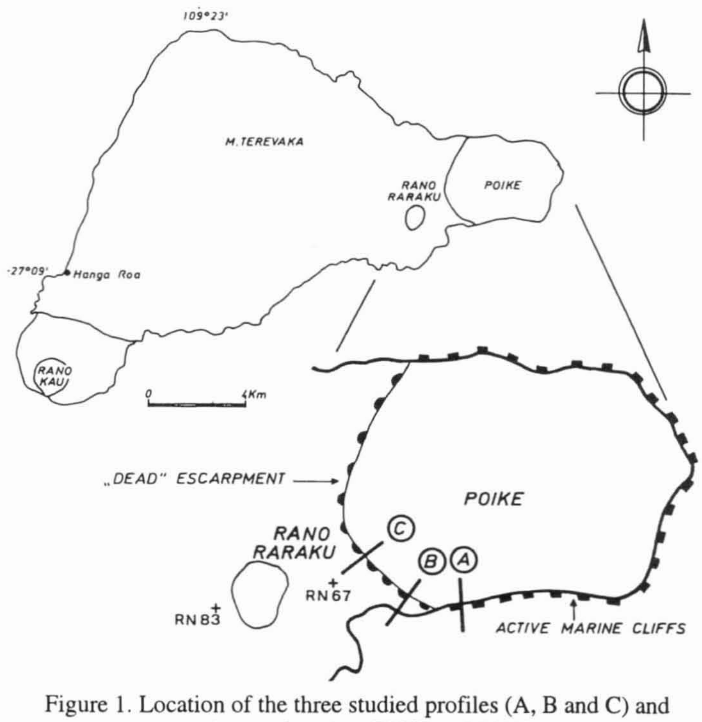

Figure 1. Location of the three studied profiles (A, B and C) and rock sample points RN67 and RN83

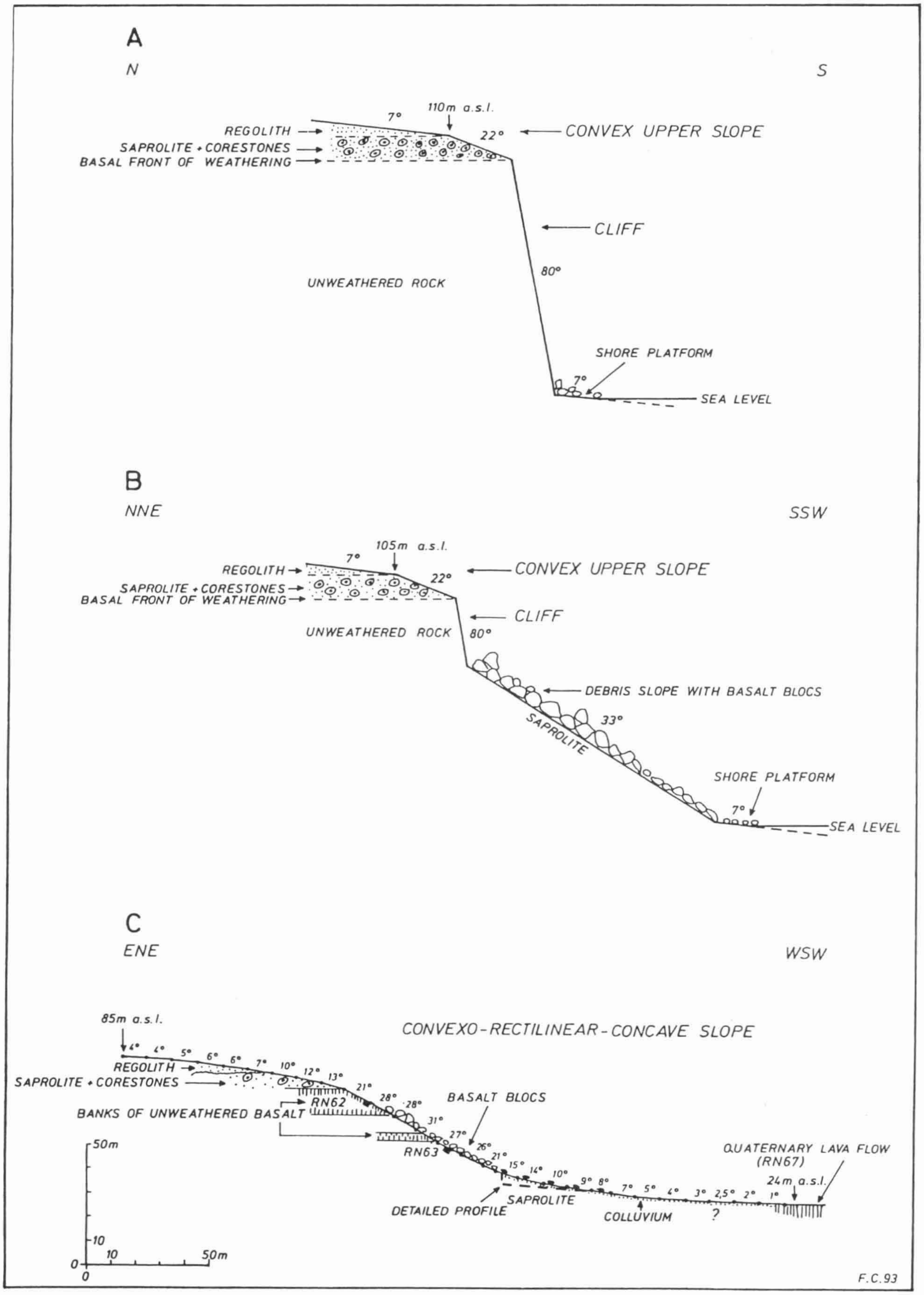

Figure 2. Schematic representation of the profiles: (A) represents an active sea-cliff, (B) a semi-active cliff, and (C) a "dead" escarpment. RN62, RN63 and RN67 refer to rock samples.

Two lava flows considered to be of utmost importance for our knowledge of the recent geomorphological evolution of both the southwestern part of Poike and the Rano Raraku area were studied with the K-Ar technique. Sample RN67, that yielded an average age of 0.51 ± 0.07 Ma, comes from the youthful lava flow which encircles the northern and northeastern slopes of Rano Raraku and contributed greatly to the fossilization of the marine escarpment developed along the southwest side of Poike. Rock specimen RN83, that gave an absolute age of 0.22 ± 0.08Ma, is representative of the lava flow of M.Anamarama thatoccupies the plain extending from M.Toa Toa to Rano Rarakuand definitively stopped the marine erosion along its southeastern cliffed border. The location of both lava samples is shown on Fig. West of Rano Raraku, the younger flow (RN83) overlies the older one (RN67).

Both K-Ar dated rock samples are porphyritic-textured hawaiitic basalts. They contain variable proportions of phenocrysts and/or microphenocrysts of plagioclase (up to 6 mm in length) and olivine set in a groundmass of plagioclase laths, clinopyroxene, opaque grains, olivine and rare volcanic glass. The major-, trace- and rare-earth element chemistries of both specimens are presented in Table 1.

Geomorphological evolution of the southwestern part of Poike

The cliffs that bound the seaward- and landward-sides of Poike illustrate how an active sea-cliff gradually passes into an inactive or "dead" marine escarpment. Three profiles across the southwestern part of Poike (Figs.1 and 2) (Pl. 1) document this transition.

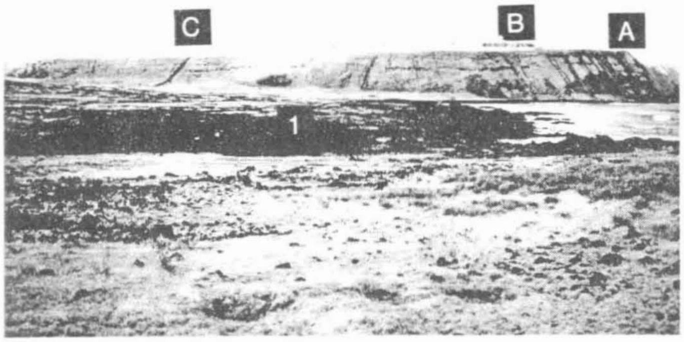

Plate 1. General view of the southwestern edge of Poike volcano with location of the studied profiles (A, Band C) and a youthful lava flow (1)
(photo: M.D.D., September 1990)

Profile A (Fig.2A) (Pl. 2) represents a typical active sea-cliff. The upper slope of the profile is convex and consists of two distinct parts. An upmost part is developed in regolith, i.e., a saprolitic material which has been transported over short distances and wherein the soil is developed. It has a general slope of 7°. Superficial sheetwash and rill formation are the dominant erosion processes here (Pl. 3). The lower part of the upper slope is developed in saprolite in situ displaying corestone formation. Its general slope is 22°. Gully erosion and initiation of small ravines are the most prominent features in this part of the upper slope (Pl. 4).

The basal front of weathering, which separates the saprolite from the underlying unweathered bedrock, gives rise to a sharp angular convex knick in the profile. On the mid-slope the unweathered rock is exposed in a subvertical cliff; by unloading and gravity, blocks fall off the cliff side. The latter accumulate temporarily on a narrow shore platform, with a general slope of 7°, that is located at the foot of the cliff. By wave action the blocks are broken down, rounded and eventually washed away. For that reason, there is no net accumulation of debris at the base of the cliff so that the latter retreats in a parallel way through a process of backwearing.

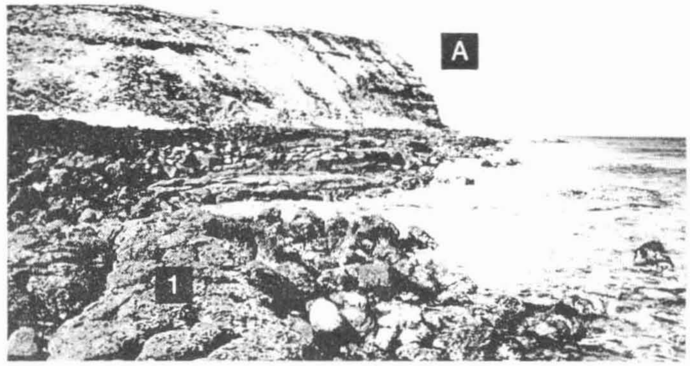

Plate 2. View on profile A and Hanga Takaure
(1, on the foreground) (photo: M.D.D., September 1990)

Profile B (Fig.2B) shows a semi-active cliff-escarpment. Here, the foot of the once fully active cliff has been fossilized by a mere narrow strip of a youthful lava flow. The upper part of the profile is similar to the one described in profile A. However, the input of blocks falling from the cliff overrules here the output on the shore platform. Therefore, there is a net accumulation of blocks on the foot of the cliff. An upward growing debris slope, with a general inclination of 33°, is formed. The bedrock beneath the debris slope is transformed into saprolite through inward weathering (Pl.5).

Plate 3. View on the uppermost slope of profile A developed in soft regolith and bearing evidence of superficial sheetwash and rill-formation. Plantings of eucalyptus as a measure against soil erosion on the middle-plan and the summit of Poike on the background
(photo: M.D.D., September 1990)

The finer material and part of the blocks that are piled up on the shore platform are removed by wave action. For that

Plate 4. View on the lowermost part of the upper slope of profile A, with corestones in situ (hammer), gullies and incipient ravines (photo: M.D.D., September 1990)

particular reason, there is no accumulation of fine colluvium on the footslope. In this transition position backwearing still prevails on the upper cliff part of the profile but downwearing takes over on the lower debris slope. With time the cliff will diminish in height and eventually disappear. From that moment on downwearing will be the predominant process of slope retreat.

Profile C (Fig.2C) illustrates the case of a once active sea-cliff that has been transformed into an entirely "dead" escarpment. Here, the foot of the original cliff has been buried by a rather thick and wide 0. 51 Ma-old Quaternary lava flow (RN67) so that any wave action is excluded. All over the slope, input of transported weathering material overrules out-

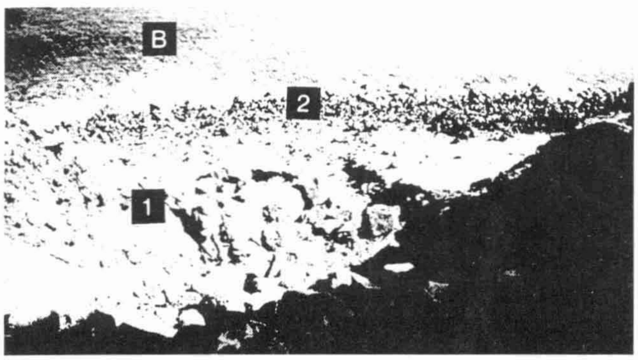

Plate 5. Downslope viewalong a revine cut in the lower midslope of profile B. The debris slope is covered with numerous angular blocks. R.L. points to the contact (1) between the in situ saprolite and the block layer. The shore platform (2) is in the background
(photo: M.D.D., September 1990)

put on the footslope. Inward weathering is taking place all over the slope and fine colluvial material accumulates on the footslope. As a result angular slope breaks are smoothed down and steep slope inclinations are diminished.

Remnants of the original cliff morphology are still perceptible where two banks of unweathered basalt (RN62 and RN63) gave rise to a short rectilinear slope portion with inclinations of 28° to 31° (Pl.7). All over the slope the bedrock is converted into saprolite by inward weathering. Downwearing has replaced backwearing resulting in a typical smooth convexo-rectilinear-concave slope morphology. The colluvial deposits which accumulate on the footslope have been studied in detail in a deep trench (Pl. 6 and 7) (see Section 4. below). They record the environmental changes that affected the area since the formation of the "dead" escarpment got started.

Soilscape evolution

Fig.3(I) shows a schematic representation of the soil-sedimentary sequence as it is exposed in a gully carved in the lower concave part of slope-profile C (Fig.2C). The exposed soil profile is about 50 m long and locally up to 4 m deep. It provides useful information about the soilscape evolution in the area. A reference profile (RP) is given in Fig.3(II). The different horizons of the profile will now be outlined from bottom to top.

The lowest horizon of the RP (unit 5 on Fig.3) contains saprolitic stones and boulders in situ, some with an unweathered core. Most of the smooth slopes of Poike, Rano Kau and M.Terevaka are covered by saprolite with unweathered corestones in situ. Such a saprolite corresponds to the lower part of deeply weathered rocks, near the basal front of weathering. However, a careful prospection did not

Plate 6. Downslope view on profile C. Part of the original cliff morphology is still visible in two banks of compact unaltered basalt (1 and 2). A deep ravine (3) exposes footslope colluvia
(photo: M.D.D., September 1990)

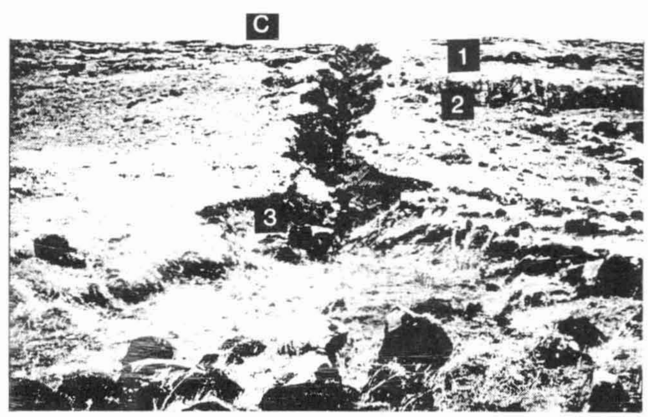

Plate 7. Upslope view on profile C. Part of the original cliff morphology is still visible in two banks of compact unaltered basalt (1 and 2). A deep ravine (3) exposes footslope colluvia
(photo: M.D.D., September 1990)

permit to detect any "complete" weathering profile, i.e. including the upper homogenized clayey, reddish part. On many places, evidence of a strong sheet erosion and traces of rill erosion can be observed.

Locally and in particular on some of the lower slopes of Poike, these superficial erosion processes are still active ensuing present-day soil management. The saprolite observed in the RP is a result of inward weathering as it was described above (3.). The position of the RP is interesting as there are only a few corestones present. Almost 95 percent of the soil volume of this first horizon is composed of a homogeneous soil matrix cut by numerous vertical biogalleries with manganese staining along their walls. The pedality of this part of the palaeosoil is also well developed. It is one of the best preserved soils on saprolite we could observe on the island.

The overlying, 10 to 15 cm-thick stone layer (unit 4 on Fig. 3) has a sharp but smooth contact with the underlying palaeosoil. The latter shows no traces of any surface horizons. These characteristics point to severe sheet and rill erosion processes. The lithic fragments, which are embedded in the stone layer, reach up to 25 cm in diameter. Originally they correspond most probably to the unweathered corestones present in the saprolites that were stripped along the higher, steeper positions of the slope. At present time, these stones have a weathering rim of only a few mm. This is also the case for the stones scattered in the overlying soil.

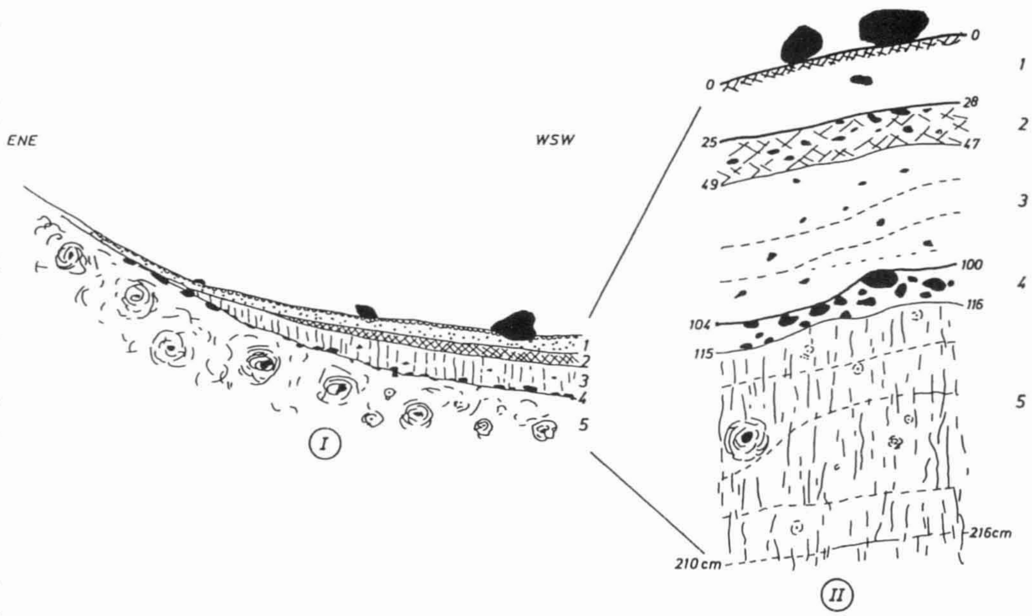

Figure 3.

I. Schematic representation of a soil-sedementary sequence exposed in a gully located at the southwest foot of Poike.
!. superficial colluvial deposits of anthropogenic origin,
2 and 3: buried soils developed in old colluvia,
4: stone layer,
5: eroded and deeply weathered soil containing saprolitic stone and boulders.

II Reference profile (RP) (depth limits in cm)
0-25 cm: Shallow soil developed in anthropogenic colluvium, with a thin humiferous horizon at the surface. The soil contains a few unweathered stone fragments.
25-49 cm: Not or only slightly eroded humiferous A horizon of a buried soil. Slightly weathered stone fragments are rather common.
49-104 cm: Weathering B horizon of the same soil containing a few slightly weathered stone fragments. On the basis of degree of pedality and color, three subhorizons may be recognized.
104-115 cm: Stone layer concentrated by erosion, mainly composed of slightly weathered stone fragments. The latter recall the poorly weathered or unaltered cores of the larger saprolitic boulders occurring in the underlying saprolite.
115-210+ cm: Remnant of a truncated deeply weathered soil. Numerous vertical biogalleries with a manganese rim are present. A few strongly weathered stones are scattered through. The larger ones still have an unweathered core (corestones). Five subhorizons could be distinguished mainly on the basis of pedality and color.

The parent material of the overlying soil (units 3 and 2 on Fig.3) most probably corresponds to the deposition of finer colluvial sediments during the final period of the environmental changes that caused already the erosion of the underlying palaeosoil (unit 5) and the deposition of the stone layer (unit 4). The humiferous surface horizon of this soil (unit 2) is well preserved and a further study of it may provide additional information about the environmental conditions governing prior to or at the moment that anthropogenic erosion and sedimentation started.

The surface layer (unit 1 on Fig. 3) is representative of the processes of soil erosion and sedimentation related to man's activities. Part of these processes are still active all over the island, mainly as a result of overgrazing. In the RP this unit is slightly stratified and contains unweathered stones and boulders, as well as fragments of charcoal and chips of obsidian. The humiferous top-surface layer is hardly a few cm thick and testifies to a still ongoing process.

The soilscape characteristics described above enable to reconstruct the following events (depth limits refer to the left side of the RP on Fig.3(II)).

1. 115 - 210+ cm. This deeply weathered soil attests to a very long period (at least several 100,000s of years) of soil surface stability and a warm climate with a considerable excess of precipitation over evapo-transpiration. A tropical rain forest most probably covered the area at that time. If there was a dry season, it must have been a short one since the soil surface remained protected by the vegetation and/or litter layer.

2. 115 cm. The strong erosion of the deeply weathered soil points to a dramatic change in the environment resulting

in a bare soil surface during at least some part of the year. This situation may have occurred under the following natural environmental conditions:

• a desert environment with so little precipitation that plants cannot grow anymore. This can be either a hot or a cold desert. However, during our prospection we could not detect any evidence of freeze-thaw or thermal retraction in the soils of Easter Island. As a consequence, cold desertic conditions are most unlikely.

• a climate with alternating wet and dry seasons. The dry season is well pronounced so that all vegetation and litter cover has disappeared at its end. Some faunal activity, such as herbivores or termites, can contribute considerably to the disappearance of all vegetation or litter cover on the soil. A population "explosion" of an animal species is not excluded, particularly on an island where newly arrived animals may find excellent food conditions without their usual predators or diseases.

• a nearby volcanic eruption covering the whole soilscape with an ash-layer sufficiently thick to kill all vegetation.

• a snow cover so thick that it doesn't melt completely in summer. If the snow cover remains for several years, all vegetation can be killed with as a consequence a strong erosion by meltwater. As we could not detect any trace of freeze-thaw, also this hypothesis can be disregarded unless it was a very short event. This is not completely excluded, particularly in view of the recent detection of very abrupt and relatively short climatic changes, among others towards the end of the Last Glaciation (Alley et al., 1993; Fairbanks, 1993).

3. 104 - 115 cm. sheet erosion nor eolian deflation are able to concentrate the coarse lithic fragments occurring in this 10 to 15 cm thick stone layer. Rill erosion could do it. This stone layer already suggests a weakening of the erosion intensity and points to a first step of net deposition. The vegetation cover is still completely or at least largely absent.

4. 25 - 104 cm. Deposition of fine-textured sediments including a few stone fragments similar to those occurring in the underlying stone layer. Most likely these materials have been deposited as a colluvium at the footslope. An eolian component is not excluded but this has to be corroborated by further laboratory research. A vegetation cover can be present at the level of the RP, but in the higher slope positions it is at least temporarily absent.

5. 25 - 104 cm. Soil development in the newly deposited sediments. The landscape is again stable with a continuous vegetation cover throughout the year. The slight weathering of the corestones, in both the soil matrix and the underlying stone layer, shows that in this period there was at least a slight annual excess of precipitation over evapo-transpiration. To reach this degree of weathering this phase must have lasted for at least several 10,000nds of years. A well developed humiferous surface horizon is present and complementary laboratory investigation will undoubtedly provide more precise information about the environment during this period.

6. 0 - 25 cm. Deposition of new colluvial, strongly heterometric sediments (including mainly silt, sand, some gravel and occasionally some boulders) of anthropogenic origin. This process is still active all over the island and is a direct consequence of overgrazing by herbivorous animals, including horses and cattle. Most likely former crop-growing activities contributed to this accelerated soil erosion. In the RP the underlying soil is not or nearly not eroded. In most areas of the island, however, this phase is eroding the pre-existing soil.

It is not yet possible to date the environmental changes shown by this soil-sedimentary sequence in an absolute way. The lava flow that contributed to fossilize the marine escarpment yields an average age of 0.51 Ma. This can be considered as a minimum age for the cliff fossilization as it is not excluded that this flow covers other older subaerial outflows. All the events starting from the fossilization of the cliff: input of transported weathering material, lowering of the original subvertical cliff to a slope gradient of about 200 to 300, inward weathering creating a soil with deep saprolite, a dramatic phase of erosion with consecutive deposition of sediments on the footslope, weak weathering of these colluvial sediments, and, finally, the human disturbance of the soilscape can all fit into the 0.51 Ma period. Considering the relatively long period needed for the development of a saprolite, the initial lowering of the cliff must have occurred in a rather short period of less than a few 100,000 years.

Comparison can be made with Flenley's (1993) sedimentary and palaeobotanical study of the cores from boreholes made in the Rano Raraku, Rano Kau and Rano Aroi lakes and ponds. Flenley's palaeoecological reconstruction goes back to about 40,000 years B.P. and possibly even further than the Last Glacial, ca. 120,000 years ago. It appears that in the temperate climatic phases the lowlands were covered by forest and the higher altitudes by a scrub vegetation. In the cold climate of the Last Glaciation the lowlands were affected by drying and a consequent opening of the forest, with more grasses and erosion; there was a cooling in the uplands, with a lowering of the limit of the woody vegetation.

Our soilscape study is located in the lowlands. None of the events described by Flenley permits to explain the dramatic erosion evidenced by the severe truncation of the deeply weathered soil. From this we conclude that this event predates the palaeoecological sequence of Flenley. The colluvial deposits of the units 2 and 3 (Fig.3) could possibly correspond to the erosion-sedimentation proposed by Flenley during the colder part of the Last Glaciation. The humiferous surface horizon of this soil (unit 2 on Fig.3) could then match with the Holocene stable surface until man's dramatic impact, or "ecological disaster" which, according to Flenley, started around 1,200 years B.P. This event and the further evolution of the soilscape until today correlates very well with the erosion-sedimentation evidenced by unit 1 (Fig.3).

Conclusion

The results of the present multi-disciplinary investigation, including geological, geochronological, geomorphological and pedological observations, not only allows to reconstruct the slope development and weathering history but also points to drastic local and/or regional environmental changes on the southwestern part of Easter Island since at least the last 0.51 Ma. Part of the latter is undoubtedly correlated with the outspoken environmental changes postulated by Flenley

(1993) for the last 40,000 years, based on palynological evidence. More detailed field and laboratory studies, as well as new datations, should permit to refine the sequence of events since 0.51 Ma and to corroborate Flenley's Late Pleistocene and Holocene sequence.

Acknowledgments

We wish to acknowledge: the Consejo de Monumentos Nacionales (Chile), the Instituto de Estudios (Isla de Pascua), the Belgian National Fund for Scientific Research, the Universidad de Chile, Gent University, Mr. Jacobo Hey Paoa, governor (Isla de Pascua) and Mr. German Hotus, Inspector of Antiquities (Isla de Pascua) .

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ITC-Publication No 93063 This research was funded by the Belgian National Fund of Scientific Research.